Chapter 3
Instrumentation Concepts, Objectives, and System Design Considerations

3-1. Introduction

This chapter expands on geotechnical concepts discussed in the previous chapter, identifies parameters in embankment structures and foundations that may need to be monitored, and provides an approach to the development of an appropriate instrumentation system. ER 1110-2-110 provides policy guidance on instrumentation for safety evaluations of civil works projects. Instrumentation necessary to assist in the evaluation of the safety of embankments is considered an integral part of the geotechnical design.

3-2. Unique Characteristics of Geotechnical Engineering

Geotechnical engineering of embankment projects requires the exploration and analysis of a wide variety of earth and rock materials. These materials must be considered for adequacy as foundations and for use in structures. Since earth and rock are created by natural processes, unlike other engineering materials such as steel and concrete, they seldom exhibit uniform properties. There is risk in every project that unexpected conditions will be encountered. The inability of exploration programs to detect in advance all potential significant properties and conditions in natural deposits requires designers to make assumptions and generalizations that may be at variance with actual field conditions. However, even though geotechnical design and construction of embankments are subject to uncertainties, visual observations supported by quantitative measurements obtained from appropriate instrumentation can provide engineers with information for checking and verifying design assumptions. Visual observations combined with instrumentation data provide the basis for assessing embankment and foundation performance and safety during actual operations.

3-3. Characteristics of Geotechnical Instrumentation

Field instrumentation is more vital to the practice of geotechnical engineering than to most other branches of engineering, in which designers have greater control over the materials utilized for construction. Therefore, geotechnical engineers must have more than casual knowledge of instrumentation. However, geotechnical engineers must recognize that, although instrumentation is a valuable tool that can be utilized for monitoring performance and safety, it is not a stand-alone solution to monitoring embankment performance. The determination of the need for instrumentation must be kept in perspective. In the words of Dr. Ralph Peck (as cited by Dunnicliff 1988) “Every instrument on a project should be selected and placed to assist with answering a specific question; if there is no question, there should be no instrumentation.” Instrumentation cannot guarantee good design, trouble-free construction, or long-term maintenance-free operation. The wrong type of instruments placed in inappropriate locations can provide information that may be confusing, or divert attention away from other signs of potential distress. It is not appropriate to mandate instrumentation at every dam or levee with the expectation that some unknown defect will be revealed during monitoring and provide a warning of an impending failure. Instruments cannot indicate signs of pending deterioration or failure unless they happen to be placed at the right location. Geotechnical instrumentation is not intended to be a sole basis for embankment evaluation; it is intended to provide data for evaluation within a comprehensive embankment safety inspection and surveillance program.

3-4. Instrumentation Objectives

The principal objectives of a geotechnical instrumentation plan may be generally grouped into four categories: first, analytical assessment; second, prediction of future performance; third, legal evaluation; and fourth, development and verification of future designs. Instrumentation achieves these objectives by providing quantitative data to assess groundwater pressure, deformation, total stress, temperature, seismic events, leakage, and water levels. Total movements as well as relative movements between zones of an embankment and its foundation may also need to be monitored. A wide variety of instruments may be utilized in a comprehensive monitoring program to ensure that all critical conditions for a given project are covered sufficiently. The most commonly used geotechnical instrumentation is described in Chapter 4.

a. Analytical assessment. Analysis of data obtained from geotechnical instrumentation may be utilized to verify design parameters, verify design assumptions and construction techniques, analyze adverse events, and verify apparent satisfactory performance as discussed below.

(1) Verification of design parameters. Instrumentation can be utilized to verify design parameters with

observations of actual performance, thereby enabling engineers to determine the suitability of the design. Instrumentation also aids engineers in modifying designs by incorporating the effects of actual field conditions. The design of earth and rockfill embankments generally entails a rigorous and sometimes complex study of forces, which must be based on conservative geotechnical assumptions concerning material characteristics and structural behavior. These generalized assumptions can leave some unknown conditions, variations, and uncertainties in the design. Observations from instrumentation systems, and an assessment of structural performance of an embankment, can help resolve these unknowns, allowing necessary refinements and improvements to be made in the design.

(2) Verification of design assumptions and construction techniques. Experience has shown that most new or modified designs and construction techniques are not readily accepted until proven satisfactory on the basis of actual performance. Data obtained from instrumentation can aid in evaluating the suitability of new or modified techniques.

(3) Analysis of adverse events. When a failure, a partial failure, a severe distress condition, a visually noted non-severe change in shape, appearance, or seepage has occurred at a dam or levee project, data from instrumentation can be extremely valuable in the determination of the specific cause or causes of the event. Also, instrumentation is often installed prior to, or during, remedial work at a site to determine the effectiveness of the improvements and the effect of the treatment on existing conditions.

(4) Verification of apparent satisfactory performance. It is just as necessary to confirm satisfactory performance of a project as it is to identify areas of concern. Positive indications of satisfactory performance are very reassuring to evaluating engineers and operators of a dam or levee project. Instrumentation data can prove to be valuable should some future variation in historic data occur, signaling a potential problem. Also, records of satisfactory performance are valuable for use in future design efforts.

b. Prediction of future performance. Instrumentation data should be used in such a manner that informed, valid predictions of future behavior of an embankment can be made. Such predictions may vary from indicating continued satisfactory performance under normal operating conditions to an indication of potential future distress which may become threatening to life or safety, and necessitate remedial action. Often earth and rockfill embankments constructed for flood-control purposes remain dry, or maintain only very low level conservation or recreation pools, except during infrequent flood events. As a result, these embankments may have existed for years without ever experiencing maximum design conditions. However, instrumentation data obtained during intermediate flood events can be projected to predict performance during potential maximum flood stage or reservoir levels.

c. Legal evaluation. Valid instrumentation data can be valuable for potential litigation relative to construction claims. It can also be valuable for evaluation of later claims relative to changed groundwater conditions downstream of a dam or landward of a levee project. In many cases, damage claims arising from adverse events can be of such great monetary value that the cost of providing instrumentation can be justified on this basis alone. Instrumentation data can be utilized as an aid in determining causes or extent of adverse events so that various legal claims can be evaluated.

d. Development and verification of future designs. Analysis of the performance of existing dams and levees, and instrumentation data generated during operation, can be used to advance the state-of-the-art of design and construction. Instrumentation data from existing projects can promote safer and more economical design and construction of future earth and rockfill embankments.

3-5. Basic Instrumentation Concepts

A determination of the number, type, and location of instruments required at a dam or levee can only be addressed effectively by combining experience, common sense, and intuition. Embankments represent unique situations and require individual solutions to their instrumentation requirements. The instrumentation system design, therefore, needs to be conceived with care and consideration for the site-specific geotechnical conditions present in the embankment, foundation, abutments, and reservoir rim. Substantial geotechnical reasons, such as unique design or difficult foundation conditions, severe downstream hazard, visually observed problems or concerns, remoteness of location, normally unmanned operation, or other concerns justify providing instrumentation. It also must be recognized that instruments are actually discontinuities, or nonrepresentative objects, introduced into soil/rock structure systems. Their presence, or the flows or displacements required to generate an observation, may alter the parameters which are being measured. Engineers installing field instrumentation must understand the fundamental physics and mechanics involved, and how the various available instruments will perform under the conditions to which they will be subjected.

3-6. Instrumentation System Planning

Planning an embankment instrumentation system requires the consideration of many factors, and a team effort of the designers (or those responsible for evaluating existing projects) and personnel having expertise in the application of geotechnical instrumentation. Developing an instrumentation system should begin with a definition of an objective and proceed through a comprehensive series of logical steps that include all aspects of the system. A series of recommended steps is provided below. This systematic planning is based on the approach recommended by Dunnicliff (1988 and 1990). The steps are listed in Table 3-1.

a. Prediction of mechanisms that control behavior. During the design of a new project or analysis of an existing project, geotechnical engineers should identify site weaknesses and areas of sensitivity. Based on these items, hypotheses regarding hydraulic, stress deformation, or strength mechanisms that are likely to affect project behavior for various conditions should be developed. The instrumentation program should then be planned around the hypotheses. For example, a soft foundation material may lead to a concern for stability and settlement; therefore, instrumentation is required to monitor pore water pressures and consolidation. Or, if abutment materials cause concern for excessive seepage, instrumentation may be selected to monitor flow quantities and solids content in the seepage.

b. Definition of purpose of instrumentation. The primary purpose of instrumentation is to provide data useful for determining whether or not an embankment or foundation is behaving in accordance with engineering predictions. When an embankment has special foundation conditions or uncommon design features, instrumentation can help in determining if design concepts for these conditions or features are being realized during construction and operation. A comprehensive monitoring program must be developed for the special conditions and features at that site. If an embankment has no special foundation conditions or uncommon design features, the need for instrumentation is less certain. Many conventional embankments of moderate height on good foundations have only minimal instrumentation.

c. Definition of geotechnical questions. Every instrument on, in, or near an embankment should be selected and placed to assist in answering a specific concern. Before addressing measurement methods, a listing should be made of geotechnical questions that are likely to arise during the design, construction, or operation phases. For the various phases, questions should cover initial site conditions, performance during construction, performance during first filling, performance during drawdown, and long-term performance. Dunnicliff (1990) listed examples of possible geotechnical questions

Table 3-1
Steps for Developing an Instrumentation System (Dunnicliff 1990)

Step	Element of Plan
a	Prediction of mechanisms that control behavior
b	Definition of purpose of instrumentation
c	Definition of geotechnical questions
d	Selection of parameters to monitor
e	Prediction of magnitudes of change
f	Selection of instrument locations
g	Selection of instruments
h	Determination of need for automation
i	Planning for recording of factors which influence measurements
j	Establishment of procedures for ensuring data validity
k	Determination of costs
l	Planning installation
m	Planning long-term protection
n	Planning regular calibration and maintenance
o	Planning data collection and management
p	Coordination of resources
q	Determination of life cycle costs

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associated with the appropriate features and parameters (see Table 3-2).

d. Selection of parameters to monitor. Typical parameters that can be monitored include groundwater pressure, deformation, total stress, temperature, seismic events, leakage, and water levels. Engineers need to consider which parameters are most significant for a particular project.

e. Prediction of magnitudes of changes. Predictions of magnitudes of anticipated change are necessary so that required instrument ranges and sensitivities, or accuracies, can be selected. An estimate of the maximum possible value, or maximum value of interest, leads to a selection of instrument range. An estimate of the minimum value of interest leads to a selection of instrument sensitivity and accuracy. Where measurements are for construction or safety purposes, predeterminations can be made of numerical values that indicate the need for immediate analysis or remedial action (hazard warning levels). Wherever possible a positive means should be developed for remediating any problem that may be disclosed during construction by results of instrumentation data. If the observations demonstrate that remedial action is necessary, the action should be based on appropriate, previously anticipated plans. Construction personnel should have contingency plans to follow in the event that hazard warning levels are reached at the site. For example, embankment construction on a site with a soft foundation would require a predetermination of hazard warning levels. The planned remedial action might include a waiting period to allow for dissipation of pore water pressure and associated gain in strength of the foundation prior to proceeding with construction. Design and construction personnel should maintain an open channel of communication so that remedial action plans can be discussed at any time.

f. Selection of instrument locations. Locations for instruments should be determined based on predicted behavior of the site. The locations should be compatible with the geotechnical concerns and the method of analysis that will be used when interpreting the data. A practical approach to selecting instrument locations includes: (1) identify zones of particular concern such as structurally weak areas that are most heavily loaded, and locate appropriate instrumentation, (2) select zones that can be represented by typical cross sections where predicted behavior is considered representative of behavior as a whole (Typically, one cross section will be at or near the maximum height of the dam, and one or two other sections will be at appropriate locations.), (3) identify zones where there is discontinuity in the foundation or abutments, (4) install some additional instruments at other potentially critical secondary locations to serve as indices of comparable behavior, and (5) locate rows of survey monuments at intervals in the longitudinal direction at appropriate elevations. If behavior at one or more of the secondary locations appears to be significantly different from the primary sections, engineers should also provide additional instruments at these secondary locations. When

Table 3-2
Examples of Possible Geotechnical Questions (Dunnicliff 1990)

Questions to Answer	Features to Assess	Parameters to Monitor
What are initial site conditions?	Foundation Abutments Drainage basin	Pore water pressure Hydrology Meteorology
How does the embankment perform during construction?	Foundation Embankment Abutments	Pore water pressure Horizontal/vertical movement
How does the embankment perform during first filling?	All features and adjacent terrain	Pore water pressure Horizontal/vertical movement Seepage Dissolved solids
How does the embankment perform during drawdown?	Upstream face Adjacent natural slopes	Pore water pressure Slope stability
How does the embankment perform during long-term operation?	All features	All parameters

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selecting all locations, the survivability of instruments should be considered. Damage during construction to the instrument, riser, or cable should be prevented by good design and temporary and permanent protection of surface exposure. Protection against vandalism should also be part of the design.

g. Selection of instruments. Reliability is the most desirable feature in the selection of monitoring instruments. This is to ensure that dependable data of adequate accuracy can be obtained throughout the period when the information is needed. Often there is a tendency to seek unnecessarily high accuracy and when accuracy and reliability are in conflict, high accuracy should be sacrificed for high reliability. High accuracy often requires excessive delicacy and fragility. Usually the most reliable instrumentation devices are the simplest devices. Where a choice exists, the simpler device is likely to have more success. The performance record of commercially available instruments should be considered. There is an inherent risk in using any electronic instrument that does not have a satisfactory track record. However, in some cases, simple instruments are not satisfactory, and more complex devices must be provided. For instance, an open standpipe piezometer may be the simplest instrument for observing a piezometric level, but the point at which the pore water pressure needs to be measured may be located where direct vertical access is impossible. In this case a less simple instrument will be required to make measurements at a remote location. In general, transducers can be placed in the following order of decreasing simplicity and reliability: optical, mechanical, hydraulic, pneumatic, electrical. When considering costs, the lowest initial cost of an instrument should never dictate the selection of an instrument. Instead, a comparison of the overall cost of procurement, calibration, installation, life cycle maintenance, reading, and data processing of the available instruments (plus a consideration of replacement cost if there is some risk the instrument should go bad) should be made. The least expensive instrument is not likely to result in the least overall cost because it may be less reliable. The cost of instruments themselves is usually a minor part of the total cost. Engineers must also keep in mind that instruments themselves can cause problems. The installation of instruments, even under the best of circumstances, can introduce discontinuities into embankments and foundations. Horizontal or vertical protecting risers or cables leading from instrumentation can have areas of poor compaction and preferential paths for seepage. Avoid horizontal conduits in the primary direction of seepage flow. Potential weaknesses introduced by an installation should be balanced against the potential benefits from the observations. Engineers need to develop an adequate level of understanding of the instruments that they select, and they will often benefit from discussing their application with a representative of the manufacturer or with an instrumentation consultant before selecting instruments. During discussions, users should convey as much information as possible about the planned application and seek out any limitations of the proposed instruments.

h. Determination of need for automation. Automated data acquisition systems (ADAS) have become a valuable means of collecting geotechnical instrumentation data. Developments in the field of electronics have made it possible to install and operate remote ADAS that provide accurate, reliable, and effective real time data collection. With increased emphasis on dam safety and the continued decrease in manpower, the advantages of providing automatic systems are numerous. Consideration should be given to providing ADAS at new projects and to retrofitting at existing projects. However, it must be understood that while ADAS can provide valuable data in a timely manner, they are only to be considered as an integral part of an overall dam safety program. An ADAS does not replace visual observations and the sound evaluation of instrumentation data provided. Further discussions on ADAS are presented in Chapter 5.

i. Planning for recording of factors which influence measurements. Measurements alone do not produce satisfactory assessments. A successful geotechnical monitoring program relates instrumentation measurements to causes. Therefore, plans should be developed to maintain records of all factors that might cause changes in the measured parameters. For example, it is necessary to record construction details and progress, geology and subsurface conditions, and results of visual observations of expected and unusual behavior. Data such as reservoir and tailwater levels, rainfall amounts, ambient and water temperatures, barometric pressure, and seismic events should also be included. Chapter 7 discusses data management, analysis, and reporting of instrumentation readings.

j. Establishment of procedures for ensuring data validity. Personnel responsible for monitoring instrumentation must be able to determine if the instruments are functioning correctly. This can sometimes be determined through visual observations or with backup systems. A backup system can be useful to confirm, or deny, the behavior indicated by some component of the primary system, even when the backup accuracy is significantly less accurate than the primary system. For example, optical surveys can be used to confirm apparent slope movements detected by inclinometers. Or, electronic or pneumatic pressure transducers used for long-term monitoring of pore water pressure can be supplemented by twin-tube hydraulic piezometers as backup. Data can also be evaluated for validity by examining consistency. For example, where consolidation is being monitored, dissipation of pore water pressure should be consistent with measured settlement, and increases in pore water pressure should be consistent with added loading. Repeatability can also indicate data validity. It is often worthwhile to take many readings over a short period of time to determine whether a lack of normal repeatability indicates suspect data. Wherever possible, the most dependable method of ensuring collection of dependable data is to provide the simplest instrumentation system available that will provide the desired data.

k. Determination of costs. Funding for instrumentation of a project should be planned during the design stage of a new project or the planning stage of an existing project evaluation. Early planning will identify the amount of funds needed, what funding is available, and if additional funding sources are needed. When the need for instrumentation is properly and correctly established, and when the program is properly planned, there should be sufficient justification for funding. Instrumentation does not have to reduce costs to be justified. Instrumentation is valuable in proving that the design is correct, or in some cases, instrumentation might show that the design is inadequate, increasing construction costs. However, the value of ensured safety and the avoidance of failure, saving the cost of damages and/or cost of repairs, makes instrumentation programs cost-effective. Cost estimates should take into consideration the cost of instruments, installation, calibration, automation, long-term protection, maintenance, and data collection and management.

l. Planning installation. Proper installation is critical to achieving reliable performance and obtaining desired information. Installation procedures should be planned well in advance of scheduled installation dates, following guidelines presented in Chapter 6. Written step-by-step procedures should be prepared, making use of the manufacturer's instruction manual and the designer's knowledge of specific site geological conditions. The written procedures should include a detailed listing of required materials and tools, and installation record sheets should be prepared for documenting factors that may influence measured data. Whenever possible, instrumentation should be installed by experienced Government personnel, rather than by contract personnel. For projects under construction, installation plans should be coordinated with the construction contractor and arrangements made for access, safety of personnel, and both temporary and permanent protection of instruments and monuments from damage. An installation schedule should be prepared that is consistent with the construction schedule.

m. Planning long-term protection. Consideration should be made for protection of instrumentation over the long-term. Survivability should be included in determining the original location of all instruments with respect to traffic patterns, operation of project maintenance equipment, and access to project visitation. Where necessary, installations should be buried out of sight in watertight containers, or adequate protection should be provided at the surface. Buried cable locations and other subsurface locations should be clearly documented on as-built drawings to prohibit future damage. In some isolated areas, it may be necessary to provide bulletproof housing. Appropriate parts and components should be available for replacement of instruments that may become inoperative for one reason or another over a long period of time.

n. Planning regular calibration and maintenance. The design of an instrumentation system must take into consideration the fact that regular calibration and maintenance of hardware will be required over the life of the project. During the design of the system, procedures and schedules should be developed for regular maintenance of readout units and any components which are accessible. Calibration and maintenance are discussed in Chapter 8.

o. Planning data collection and management. Procedures for collecting, processing, presenting, interpreting, and reporting instrumentation data should be developed prior to installation of the system. The effort required for these tasks should not be underestimated. Too often data collection files become filled with large quantities of partially processed and undigested data because sufficient time and funds were not appropriated for activities required after the instruments were installed. With the development of computerized data collection, processing, and presentation procedures, overall manual effort has been greatly reduced. However, the limitations of computerization must be recognized. No computerized system can replace engineering judgment, and engineers must make a special effort to ensure that measured effects are correlated with probable causes. The tasks of interpretation, judgment, and implementation must be performed by competent personnel rather than computers. Data management and analysis are discussed in Chapter 7.

p. Coordination of resources. Tasks to be considered during the monitoring program include planning regular calibration and maintenance of instruments, instrument replacement procurement, installation, and calibration, data collection, and data management. When tasks are assigned, the person with the greatest vested interest in the data should be given direct responsibility for producing the data accurately. Instrumentation personnel need to have a background in the fundamentals of geotechnical engineering, and be reliable, patient, and motivated. In addition, they need to demonstrate attention to detail. Qualifications for personnel are presented in paragraph 3-8.

q. Determination of life cycle costs. Once planning for the system is completed, the cost estimate for the tasks suggested in paragraph 3-6*k* should be updated. Care must be taken to ensure that sufficient funds are provided to cover all aspects of the program, including instrument maintenance and the data collection and processing costs for the life of the project.

3-7. Procurement

The specialized nature of instrumentation facilities and the care required in the procurement, installation, and calibration of equipment demand that these features of work be retained under close operational control of qualified Corps of Engineers personnel. Direct procurement by the Government of instruments, cable, tubing, and indicating or recording equipment, and similar items not normally encountered in construction work, is recommended.

3-8. Personnel Qualifications and Responsibilities

A variety of tasks must be accomplished for an instrumentation program to be successful. The tasks include instrumentation installation, calibration, automation, long-term protection, maintenance, and data collection and management. Generally, these responsibilities can be delegated among individuals with diverse skills and backgrounds, or the same individual can be responsible for various tasks. Responsibilities should be very clear, communication being the single most important link among the various personnel (Table 3-3). The overall scope of the work should be supervised by a senior-level geotechnical or instrumentation engineer.

a. Project inspection personnel. Inspection of the project features should be accomplished on a routine basis during both construction and project operation. The actual schedules should vary depending on the criticality of the particular feature. A project engineer, project superintendent, or maintenance foreman are the most likely candidates, but anyone at the project with proper training can accomplish the inspections. As an example, the inspector should look for evidence of seepage or distress in the embankment or abutments, particularly springs, seeps, or boils developing along the downstream toe of the embankment, or zones of settlement, caving, bulging, or other distress in the embankment. Remarks should be noted on a preprinted form, and if deemed necessary, the appropriate District personnel should be notified immediately.

b. Instrumentation and/or automation equipment installation personnel. Installation should be coordinated by the senior-level geotechnical engineer, since proper installation of instruments and automation equipment requires specific knowledge and requirements.

c. Data collection personnel. It is highly recommended that permanent project employees be assigned data collection responsibilities. These employees should be properly instructed by the senior-level geotechnical or instrumentation engineer, and receive training on the importance of the tasks. Project personnel responsible for collecting data are too often temporary or summer hires who have limited knowledge of the geotechnical questions of concern. If permanent personnel are assigned to accomplish this task, they too often do not understand or enjoy the work, thereby affecting data quality. Repeatedly training part-time employees is difficult and time-consuming. There are three options when considering personnel to read manual instruments. The task of reading the manual instruments can often be combined with the maintenance of automation equipment if the data collection is partially automated. A second option is to hire a permanent employee whose job description includes the reading of manual instrumentation on a District project or area-wide basis. Ideally, a single individual at the District or project level should make the manual readings, since this allows for consistency of data, and also allows the individual to become familiar with the historical behavior of the instruments. A third option is to contract the work out, but this is not generally recommended because of the possible turnover in the contractor’s reading personnel.

d. Instrumentation and automation equipment maintenance personnel. The maintenance of instrumentation and automation equipment is becoming increasingly more complex due to the partial automation of many Corps projects. A discussion on the personnel requirements relating to maintenance is included in paragraph 8-2.

Table 3-3
Personnel Responsibilities

Title	Responsibility
Senior-level geotechnical or instrumentation engineer	Coordinates and supervises the entire instrumentation program, including design of instrumentation and automation equipment, selection, procurement, and installation. Provides training to instrumentation personnel and assists in personnel decisions. Should assist in data interpretation and analysis and provide technical assistance or guidance to other geotechnical engineers responsible for final data analysis.
Project inspection personnel	Inspect the project during both construction and operation. Make notes of changes (seepage, boils, caving, etc.) and notify District personnel if necessary.
Instrumentation and/or automation equipment installation personnel	Responsible for initial instrumentation and installation; assure initial readings are correct and make necessary initial calibrations.
Data collection personnel	Collect data from manually read instrumentation. May also enter data into the computer.
Instrumentation and automation equipment maintenance personnel	Maintain instrumentation and automation throughout life of the project. Recalibrate and replace instruments as necessary.
Data entry personnel	Enter collected data into the computer. May also be responsible for collecting data from the field.
Data management, reporting, and plotting personnel	Process data from all District projects. Work with senior-level geotechnical or instrumentation engineer. Work with various software programs, data transfer from remote sites, programming, creating reports, and submitting data plots.
Instrumentation program manager	See senior-level geotechnical or instrumentation engineer.
Review and analysis personnel	Review and analyze final data to assure the project is performing in accordance with design. Also notify maintenance personnel of inaccurate readings or malfunctions.

e. Data entry personnel. The task of data entry is often combined with other tasks. Data entry can be at the project site by data collection personnel, or in the District office by data management personnel. Data entry can be handled by non-geotechnical personnel, such as information management personnel. However, since initial error checking should be accomplished at the data entry level, it is highly recommended that a person familiar with the instruments enters all data.

f. Data management, reporting, and plotting personnel. This position is generally filled at the District level by an engineering technician with strong computer skills, who processes the data from all District projects. This person must work closely with the senior-level geotechnical or instrumentation engineer who is responsible for coordination of the entire instrumentation program. Tasks include interrelating with numerous software programs, data transfer from remote sites, programming, creating reports, and submitting data plots. It is also necessary that the individual be trained in data collection and field maintenance so that he or she better understands the instruments and automation equipment in use.

g. Instrumentation program manager. The overall management of an instrumentation program should be supervised by a single instrumentation or geotechnical engineer, whose responsibilities should include instrumentation and automation equipment design, selection, procurement, and installation. He or she should coordinate all of the tasks listed above, provide training to the instrumentation personnel, and assist in personnel decisions. As a minimum, this person should assist in data interpretation and analysis, and provide technical assistance or guidance to other geotechnical engineers responsible for final data analysis.

h. Review and analysis personnel. Senior-level geotechnical or instrumentation engineers must be involved in the final review and analysis of all instrumentation data. It is possible that this task can be accomplished by the instrumentation program manager, but other engineers must be involved so that multiple reviews are being accomplished. The program manager and the technical reviewers should establish data review schedules and formulate reports on a consistent and frequent basis.